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J. W. Testa, K. Kovacs, J. Francis, A. York, M. Hindell, and B. Kelly

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Institute of Marine Science
School of Fisheries and Ocean Sciences
University of Alaska Fairbanks
Fairbanks, Alaska 99775-1080

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Abstract: A workshop involving statisticians and biologists was held from September 20-22, 1992 at the University of Alaska Fairbanks. The sessions included brief presentations by one or two people on analyses that have been tried, followed by discussion of those approaches, suggestions and discussion of new approaches. The workshop made clear that a set of cohesive analysis protocols would not suffice for the variety of data being collected with TDRs and related instruments. At the same time, there was unanimous agreement that the workshop made obvious many similarities in the problems faced by different researchers and that a significant start had been made at addressing some of those problems. Many felt that the workshop's greatest accomplishments involved connecting marine mammal researchers with statisticians expert in appropriate methods. These collaborations are expected to improve the analysis of the data sets discussed during the workshop and, moreover, to provide models for other workers analyzing dive data from a variety of marine organisms.

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SEATTLE WA 98105-4631

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ROBERT J. SILVERMAN

Analysis of Data from Time-Depth Recorders and Satellite-Linked Time-Depth Recorders: Report of a Technical Workshop

September 20-22, 1992

Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775-1080

CONTENTS

PREFACE

The increasing sophistication of Time-Depth Recorders (TDRs), and development of Satellite-Linked Time-Depth Recorders (SLTDRs) have lead biologists in the field of diving behavior to an enviable, but still serious dilemma. The richness of the data gathered with these tools has exceeded our collective expertise in interpreting them. The relatively simple questions like, "how deep can a seal dive?" have been answered with megabytes of complicated data begging more sophisticated questions and more sophisticated analyses. This workshop was proposed after discussions during a symposium on Recent Advances in Marine Mammal Science (London, April 9-10, 1992) repeatedly returned to inadequacies in our analyses of diving records. In organizing this workshop, it was recognized that the interest would far exceed the optimal group size for a productive discussion. As organizer, I apologize that a great many people that might have contributed could not be accommodated, but I tried to invite experts to represent a broad range of pinniped diving behavior and bring them together with experts in statistical analyses appropriate for data collected with archiving time-depth recorders and the satellite-linked versions of these. It is my hope that this report will find circulation amongst those interested in these problems and stimulate correspondence and collaboration.

Ward Testa, Convener

May 10, 1993

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The workshop and this report were made possible through funding provided by the Office of Naval Research, grant N00014-92-J-4086. We wish to especially thank Ms. Maggie Billington for expert coordination of participants' travel, and the organization of facilities and staff support necessary for a productive workshop.

PARTICIPANTS AND INTERESTS

David Brillinger Statistics Department University of California Berkeley, CA 94720 brill@stat.berkeley.edu	-	applications of statistics in scientific investigations
Mike Castellini Institute of Marine Science University of Alaska Fairbanks Fairbanks, AK 99775 ffmac@acad3.alaska.edu	-	diving physiology and behavior
Dan Costa Biological Sciences Division Code 1141 Office of Naval Research 800 N. Quincy Street Arlington, VA 22217 costa@nosc.mil	-	foraging ecology and energetics of pinnipeds and penguins
Dan Crocker Biology Department 273 Applied Sciences University of California Santa Cruz, CA 95064 dcrocker@cats.ucsc.edu	-	diving behavior in northern elephant seals
Kevin Engle Institute of Marine Science University of Alaska Fairbanks Fairbanks, AK 99775 ftkre@acad3.alaska.edu	-	remote sensing
John Francis Cascadia Research Collective 218 1/2 W 4th Avenue Olympia, WA 98501	-	behavioral ecology of pinnipeds
Roger Gentry National Marine Mammal Laboratory 7600 Sand Point Way NE Seattle, WA 98115 R.GENTRY/Omnet	-	behavioral ecology of pinnipeds - esp. foraging/diving
Roger Hill Wildlife Computers 20630 NE 150th St. Woodinville, WA 98072	-	design, manufacture and 'support' of TDRs and SLTDRs
Sue Hill	-	design, manufacture and 'support'

Wildlife Computers - of TDRs and SLTDRs
20630 NE 150th St.
Woodinville, WA 98072

Mark Hindell - ecology of pinnipeds and penguins
University of Tasmania
G.P.O. Box 252C
Hobart, Tasmania 7001
Australia
mark@diemen.utas.edu.au

Brendan Kelly - Behavioral ecology of pinnipeds, sea ice ecology
Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775
fnbpk@acad3.alaska.edu

Kit Kovacs - behavioral ecology and energetics of ice-breeding phocid seals
Dept of Biology
University of Waterloo
Waterloo, Ontario N2L 3G1
Canada

Bernie McConnell - ecology of seals/satellite telemetry
Sea Mammal Research Unit
High Cross, Madingley Road
Cambridge, England CB3 0ET
us_bjm@vaxc.nerc-bas.ac.uk

John Monahan - statistical computing, time series and multivariate statistics
Dept of Statistics
NC State Univ.
P.O. Box 8203
Raleigh, NC 27695-8203
monahan@stat.ncsu.edu

Robert Newburgh - representative of Office of Naval Research
Director
Biological Sciences Division
Code 1141
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217

Gary Oehlert - statistics, trend analysis, data analysis
Dept of Applied Statistics
Classroom Office Building
University of Minnesota
St Paul, MN 55108
gary@umnstat.stat.umn.edu

Sastry Pantula - statistics, time series analysis
Dept of Statistics
NC State Univ.
P.O. Box 8203
Raleigh, NC 27695-8203
pantula@stat.ncsu.edu

Pham Quang - statistical data analyst
Department of Mathematics
and Statistics
University of Alaska Fairbanks
Fairbanks, AK 99775
ffpxq@acad3.alaska.edu

Jason Schreer - diving behavior of Weddell seals
Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775
ftjfs@acad3.alaska.edu

Brent Stewart - population and foraging ecology and marine mammal telemetry
Hubbs-Sea World Research
Institute
1700 South Shores Road
San Diego, CA 92109

Ward Testa - Population ecology and behavior of pinnipeds
Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775
fnjwt@acad3.alaska.edu

Geoff Watson - statistics with a geometrical flavor
Department of Mathematics
Princeton University
Princeton, NJ 08544-1000
gsw@math.princeton.edu

Anne York - statistics, data analysis, population dynamics
National Marine Mammal
Laboratory
7600 Sand Point Way NE
Seattle, WA 98115
aeyork@u.washington.edu

Session I: Introduction

Chair: Roger Gentry
Rapporteur: Kit Kovacs

Opening Remarks

Ward Testa welcomed the workshop participants to the University of Alaska Fairbanks, and identified the rationale for the workshop and the basic task at hand for the following three days. The purpose of the meeting was to identify common problems in dealing with 'dive data' as collected by time-depth recorders (TDR's) and satellite linked time-depth recorders (SLTDR's), and to seek solutions for dealing with the quantitative analyses of these data while addressing the various questions of interest to marine mammal biologists (and others working with diving animals).

Historical Perspective

Roger Gentry provided a brief history of the development of the instrument packages that have been used by biologists to collect data on diving. He discussed the progress that has taken place from the early, stip-chart analog dive recorders to the digital recorders that are now available. Some discussion ensued regarding the size, memory and reliability of the recorders now available, and the concomitant changes in the complexity of questions that can be addressed and the diversity of organisms that can be studied. Gentry identified two primary classes of questions that biologists are attempting to answer using information from TDR's and SLTDR's - 1) direct/focussed 'simple' biological questions about the diving abilities of aquatic animals and how they spend their time when at sea and 2) analyses of long term trends and hidden complexities of long term data collected in time series, or ontogenetically. He further clarified 'the mission' for the group of data analysts, biologists, and engineers that the workshop had brought together.

Biological Questions

The participants were invited to introduce themselves and their particular interests (pg 3). This resulted in an impromptu communications session that was repeated throughout the morning at various times as the need arose to define statistical and analytical terms for the biologists and biological terms and problems for the data analysts.

Until the advent of TDR's the lives of marine mammals, birds and reptiles at sea were basically unknown; we knew next to nothing about how these animals spend the majority of their lives. Although some information on diving physiology had been gleaned from experimental laboratory situations, little was known about their actual abilities and how this potential was exhibited in their daily lives. TDRs have provided records of phenomenal

diving by some beasts that will require rewriting our classical beliefs on the physiology of diving. In addition to some spectacular data points, we also are getting sufficiently large data bases on individual species to ask questions beyond simply how long or how deep a particular species can dive.

Studies of diving now are attempting to assess the influence of various life-history and environmental parameters on diving behavior. For example - What are the effects of body size, age, gender, season, reproductive condition, bottom topography, or forage availability on diving behavior? The discussion of biological questions lead to a brief discussion of some practical aspects of capture, device attachment, selection of study specimen, sample size (and expense) problems, and recovery of the data from recorders that store data.

Technical Approaches

Three basic systems that are currently employed by biological researchers to document diving behavior were described by experts who have been active in the development and deployment of the respective systems.

Wildlife Computers: Sue Hill outlined the objectives that guide her and Roger in development of TDR systems. Their current focus is expansion of memory and reduction of size (while remaining affordable). She described the current MK5 TDR that Wildlife Computers sells and services; it is a data logging recorder with sensors to monitor depth, temperature, light level, and conductivity. The diving behavior of animals is sampled according to user-directed protocols. The effects of various sampling regimes, especially sampling interval, on variables measured during each dive were discussed and the effects of increasing the sampling interval on the "shape" of a dive profile were illustrated. In general, increasing the sampling interval reduces the possible complexity (up and down movements) of the dive profile and biases the estimate of maximum depth downward.

The Hills also discussed how their satellite-linked TDR system operates. For transmission to satellite and subsequent relay to receiving earth stations using the Argos system, dive data must be greatly condensed. The current system employed by the Hill's SLTDR's reduces each dive to two parameters, maximum depth and duration, and increments counters in six user-defined categories for each variable. These counters are then transmitted to orbiting satellites as histogram data in 6-hour blocks. There are various options for the sampling intensity and duty cycling of transmissions, and the limitations of these records were discussed at some length so that the statistical analysts could start digesting the complexities that the mode of sampling imposes on the data sent to the satellite.

A brief discussion of the available support software took place at the end of the session. Programs are available for

plotting depth profiles, as well as analyzing and reducing dive profiles to summary variables (e.g., maximum depth, duration, ascent and descent rates, bottom time, etc.) observed with each dive.

Sea Mammal Research Unit (SMRU): Bernie McConnell presented an overview of telemetry systems that biologists use to track the movement and behavior of animals at sea. He compared 1) simple acoustic tracking of individual seals that allow for intensive sampling of a specific animal's behavior, 2) VHF radio telemetry systems that can be used to monitor a number of animals simultaneously over relatively short distances and 3) satellite systems that allow for long distance sampling of movements, diving and environmental variables. He focussed on the satellite telemetry systems that the SMRU is using to track southern elephant seals and to elucidate correlates between the seals' behavior and their oceanic environment.

A discussion, principally involving McConnell, S.Hill and R.Hill, clarified for the rest of the participants how the SMRU satellite transmitters sample and transmit information. Data from individual dives are compressed into a standard form (including depth and swim speed profiles taken at one fifth of dive duration) and are transmitted. In addition, summaries of these dives, over six-hour periods, are transmitted. The actual data which are received in the lab depend upon the behavior of the seal (primarily the amount of time that it was at the surface) and the availability of the satellite. Because of the polar orbit of Argos satellites, more information can be received from animals at high latitudes.

Wartzok/Kelly: Brendan Kelly introduced an underwater acoustic tracking system that he and D.Wartzok have been using to document the diving behavior of ringed seals (Phoca hispida). After a brief session on the life-history of ringed seals that provided background for the questions being addressed by his study, Brendan described the hydrophone array used to track seals equipped with an acoustic transmitter. The 3-dimensional position of the seal is determined by the time delay in signal reception at each of 4 hydrophones. Although the system has a much more limited areal focus than those described previously, this method provides the most complete spatial representations of a seal's dives.

Discussion

After a prolonged and multidisciplinary discussion, our many research questions distilled into three basic classes of analytical problems. The first is accurately and quantitatively describing dives or bouts of dives from the very simple variables being used (typically depth and time). The problem involves classifying "shapes" or types of dives, and bouts of similar dive types. An important caveat to this discussion is that virtually all dive data collected to date provide estimates of dive "shape"

only with regard to depth vs time (although the illusion of space is difficult to avoid when one examines a strip chart trace of a diving record). It must be remembered that the subjective perception of dive "shape" from such simple dimensions is quite limited, and possibly misleading, without additional data on actual movements or behaviors. Recognizing this, how do we objectively define classes of dives from such records or determine start and stop points to bouts? The objective here is to process dive records objectively to a greater extent than is possible now with the current method of 'eye-fitting' each dive in a record or making relatively subjective guesses regarding the similarity of dive forms. It was suggested that this problem may involve pattern recognition systems, runs analyses or 'Markov chain-like' analyses.

The second class of problems involves correlation analyses to address such questions as: how diving behavior (as measured with recorders) is related to various life-history parameters, breeding condition, etc.; or how aspects of the environment (water temperature, bathymetry, light levels, etc.) relate to diving behavior. Further, our simple classifications based on depth and time may be testable against more detailed data that come closer to the actual functions of dives. Such analyses may involve discriminant function, cluster, or some other multivariate approach.

The third class of problems is concerned with time series. They involve ontogenetic or long-term studies that produce records of significant duration. Questions about the impact of season or development on diving behavior are of primary concern. Classical time-series analysis measures may be the answer if the assumptions of the models can be met.

Session II: Dive Classification and Bouts

Chairman: Mark Hindell
Rapporteur: John Francis

Classifying Dives

The group began a discussion of possible statistical methods that could be used to objectively classify different dive types that are subjectively apparent in TDR records. Mark Hindell summarized efforts to date with southern elephant seal data. In that work, dives were separated subjectively by the number and variability of up and down movements (wiggles) near the bottom of a dive. Six dive types were recognized in this manner, but principle components analysis (PCA) using descent rate, ascent rate, number of wiggles, size of wiggles, and duration of bottom time as variables separated dives into only 2 or 3 categories. Mark's conclusion was that more variables would be needed in order to use PCA to discriminate dives. A similar conclusion was reached by Guy Oliver, working on northern elephant seal data.

Gentry reported that northern fur seal dives were also separated subjectively into 3 types: "U-shaped", "flat-bottomed" and "depth reversal" dives, with the last category subdivided further based on whether reversals occurred during descent, ascent or near the bottom of the dive. Gentry commented that he found 90% agreement in replicate classification of the dives. Others encountered similar repeatability.

A discussion followed on the variables that are or might be included in a dive analysis algorithm to increase discriminatory power.

Wiggles: These are the vertical reversals in a dive profile, (termed "prey pursuit movements" by Bengtson and Stewart 1990, Polar Biology). Gentry is looking at them in relation to depth and temperature under the premise that they are associated with prey searching and capture. Most agreed that this premise is likely and this feature is a common one in data from most species studied so far, but no one has data to confirm this.

Bottom time: McConnell advocated the need for a strict (or at least explicit) definition of bottom time for those who choose to calculate it "on board" the data collection device. Wildlife Computer's software uses time spent below 85% of maximal depth, or any user programmed percentage of maximum depth. However, the concept of "bottom time" becomes difficult to apply with certain dive profiles, such as a U-shaped dive, or dives with a flat "bottom" followed by a sharp, deep "spike to a deeper depth. Crocker illustrated this problem with a dive type seen in records from pregnant northern elephant seals where a flat "bottom" is followed by a deeper spike. R.Hill suggested that one could choose that percentage based on a frequency distribution of depth ranges within each dive to identify the bottom.

Costa raised the question of a functional definition for bottom time and pointed out how our choice of parameters is context dependent. For some species, the bottom is where foraging occurs and that may be different from a species that forages en route to and returning from a true bottom. There also is difficulty relating bottom time or wiggles to detection of a prey patch or successful foraging vs unsuccessful foraging. Most of the biologists agreed that the bottom of a dive profile is likely to be biologically significant, and may be where seals are foraging, but association of bottom time with foraging or any other activity hasn't been established beyond doubt.

Velocity: McConnell noted that once we have swim velocity data we may be able to better categorize dive types and then return to old records for reevaluation. It is likely that we will have velocity meters on all TDRs in the future. Velocity meters may not be so valuable in some species such as Otariids, where velocity is almost constant at 2m/s. Even in these cases, however, velocity meters would be valuable for interspecific comparison. McConnell pointed out that meters may only provide an index of swim speed due to the fact that they stall at certain low speeds and that the flow of water into them is affected by the hydrodynamics of the water flow over the seal. Ways are being examined to resolve this problem by looking at the relationship between rates of change of depth from the depth transducer and the associated speed measurements. Kelly's ringed seal data, based on three-dimensional locations at 4-5 second intervals, provides accurate swim speeds without the hydrodynamic problems cited by McConnell.

Other parameters: In a study of northern fur seals, York found two additional parameters were helpful: 1. the integral of area under the curve and; 2. arc length. Hill has suggested that the simple ratio, average depth/maximum depth, conveys unique information about dive "shape". McConnell also suggested that looking at horizontal displacement while foraging would help us classify dives as traveling or foraging or both. Along those lines, the ability to directly detect prey consumption will be essential to classifying foraging dive types.

Suggested analytical approaches to classification of dives

Although we seem to be looking for a numerical validation of our subjective criteria, we don't, a priori, all agree on a classification scheme. Subjectively, there appear to be some dive types (based only on time-depth records) shared by several species, but there are also many differences between species. Monahan suggested that the group agree on a few dive types and develop algorithms that describe them, but there are problems with applying simple algorithms. Crocker gave an example from northern elephant seals of a flat bottom dive having either a positive or negative slope at bottom depending on whether or not the female is pregnant. The risk to such algorithms is that you

may overlook some interesting relationships. This is especially true in the case of classification algorithms used on SLTDR's.

The possibility and desirability of classifying dives "on board" the microprocessor is open to debate. With the approach McConnell uses (describing the dives as a series of 5 depths and duration), one can partially process the dive without classifying type. Oehlert suggested taking a series of greater resolution (10 depths) to give standardized dive profiles, then comparing the 10 depth coordinates directly to classify the dive using a tree classification or discriminant analysis. For example, Breiman et al. (1984) give an example of classifying ships into types on the basis of the intensity of their radar reflections at a sequence of angles. We could use the same methodology for classifying dives on the basis of depth at a sequence of times. This approach would use the depth profiles more directly, instead of derived variables, although one could add wiggles or other derived variables to the classification process. Oehlert also warned against classifying dive type "on board".

Quang proposed an algorithm for dive classification which uses the area enclosed by the dive profile and the sum of the changes in angle across all sample points. The angle sum would thus be considerably higher for a dive with wiggles. Several in the group comment that this approach does not tell you where the wiggles are and also that the method is sensitive to the depth sampling interval. Again, standardizing the dive by taking a set number of depth readings, and possibly weighting bottom dives more heavily might make this approach useful.

Hindell directed discussion toward the question, "What multivariate techniques are best." Monahan suggested prospecting with various techniques until the data 'are screaming at you'. There was discussion on when over the next two days we could try any of these procedures. Raw data sets were available, but not with dives already classified so that objective and subjective classification could be compared. Nevertheless, it seemed that the exercise would be instructive. However, the data we had at the workshop were not all sufficiently "preprocessed" for exploratory data analyses, and the preprocessing is often more difficult than the statistical analysis. One needs to have a set of identified profiles to work with. Hindell suggested that this may be one of 4 working group problems we could assign later. The possibility of prospecting some of the available data sets was tabled for the time being.

Identifying Bouts

Previous methods of defining dive bouts have been based mostly on behavior related to diving (i.e., surface intervals) as a flag to identify when dive patterns changed. Log-survivorship curves and normal-transforms of the log of surface intervals (probits) have been used to plot surface intervals and find discontinuities, but selection of these discontinuities has been

subjective. If one continues to use interdive intervals as a bout-ending criterion, Oehlert suggested using a normal-normal plot to check for discontinuities. If interdive intervals (possibly transformed) follow a normal distribution except for bout ending intervals (which are longer), then the bout ending intervals may appear to be outliers with respect to the other intervals. One way of identifying these outliers is normal probability plots (also called qqplots, normal plots, rankit plots, etc.; e.g., Sec. 6.6 of Weisberg 1985).

Gentry offered an example of fur seal dives in which depths shifted, but interdive interval remained constant. Another example was given of elephant seals shifting from V-shaped dives to flat-bottomed dives with no change in surface interval. In Hooker's sea lions and northern elephant seals the bouts may be several days or weeks long! It was pointed out that the Probit analysis could be applied to other dive variables. It also was suggested that a ratio of interdive interval to some other dive variable might be used. However, the group questioned whether we can expect changes in dive behavior to carry a consistent 'flag', such as a change in interdive interval. Identification of bouts is an attempt to identify a series of behaviors that are related. If we are looking for runs of similar behavior types, we probably should not get distracted by the so-called bout-ending criterion, but consider the possible functional explanations for dive bouts when deciding how they should be treated.

Hindell framed the question more formally: 'how do we statistically detect changes in behavior?' Brillinger suggested measuring "level crossings" as is done in analysis of earthquakes: e.g., draw a line at 50m across a dive record and record instances where the record hits or exceeds that value. If it is rare you get a Poisson distribution. Another approach is to monitor the ratio of the short-term running mean to a long-term mean....a sudden change would indicate a change in behavior. There are lots of models to use in analyses of this kind of data (e.g., using a power spectrum as a point process or using moving spectra). Because seal bouts are more predictable and regular than earthquakes, such methods might work better on diving data.

Oehlert suggested "change point techniques", used in quality control, that you can use to assess both dive type and interdive interval. The idea is that we observe a sequence of data values X_j which may, at some point, have a change in average value. The problem is to detect the change and determine when it occurred. If the data are interdive intervals, then we would be looking for a change in mean interdive interval. If the data are 0's and 1's representing two dive types, then a change in mean is a change in the mixture of the dive types. The number of available techniques is huge, and includes variations on the control chart [cumulative sum methods (e.g., Hawkins 1987), exponentially weighted moving averages (e.g., Lukas and Saccucci 1990), likelihood ratio tests (e.g., Quandt 1958 and many others), nonparametric methods (e.g., Pettitt 1979), and other methods.

R. Hill suggested taking the first dive + surface sequence and comparing it to the next, then if it were the same use it or the average to compare to the following segment. Ian Boyd (et al., in prep.) is using an approach like this on antarctic fur seal data. A new bout is marked when the new dive + surface sequence does not match the prior sequence to within a defined tolerance. Brillinger called it a "sliding autocorrelation", but it would have some type of internal scaling. He also suggested a number of possible approaches. The "correlation time" concept used in engineering might be applicable here. One could use an "autocovariance function" to estimate bout lengths. "Time work studies" used by AT&T in the 30's is similar to what we're doing (Shell 1986).

Another approach is the use of Markov chain type models to determine time spent in a certain state. A change in state would be the end of a bout. Brillinger gave a brief description, explaining that if a time series is a Markov chain, then it will move randomly, with estimable probability, from one state to another. Probabilities of transition can be assigned for each possible transition type. Such an analysis was used by York and Gentry on northern fur seal data and they found that it predicted the next dive but not the one following....i.e., it had "poor memory". Gentry commented that it was obvious that certain dive types were predictably paired. Transition probabilities of a Markov chain provide a test, and measure of this. The problem was that they were clustered in groups separated by gaps but the gaps were not recognized in the time series analysis. No weight was given to the transitions.

Brillinger noted that resting times and their relation to dive types could be analyzed separately. (He clarified in this discussion that he did not agree that it was a good idea to analyze states, such as dive types, subjectively.) Also, he stressed that a true Markov chain refers back only to the prior state, whereas we probably need something with a longer memory (hence, "Markov chain-like"). One might set the states to A=surface and B=diving, or A=surface and B-E=dive types. Brillinger showed some plots he did on Stewart's and Testa's data sets testing for a Markov distribution. He explained that with an autocorrelation analysis you could use the same data set but just look at effects over longer distances. A thorough analysis might proceed as follows:

Step 1: define when dive ends and begins
Step 2: define dive types
Step 3: convert to states and their lengths
Step 4: perform a Markov analysis or variant thereof

Several introductory texts and relevant journal articles are listed in the References.

Session III: Sampling Constraints and Information Loss

Chair: Bernie McConnell
Rapporteur: Ward Testa

A handout on sampling constraints outlined the design of behavior studies involving TDRs and SLTDRs (Appendix A). This was intended as a framework for discussing the problems related to sampling processes, and the resulting discussion emphasized the problems of sampling frequency for the data recorder, processing the data so as to maintain information important to the purpose of the study, and the recovery of the processed information. There was quick agreement on the basic philosophy of sampling presented by McConnell and the discussion moved to particular examples.

McConnell illustrated sampling biases encountered by SMRU biologists in studies on gray seals with SLTDRs. Apart from biases introduced in the capture of particular animals that may be unrepresentative of the target population, SMRU studies have encountered gaps in the data transmitted by satellite that were associated with the behavior being studied and satellite availability. Satellite transmitters were programmed to transmit the most recent diving behavior, but successful transmission to satellite is dependent on the amount of time the seal spends at the surface. Hence, the behavior influences the likelihood of collecting data on that behavior, leading to biased observations.

Brillinger and Watson both pointed to similar problems known as "length biased sampling" (sampling which overrepresents states having the longest durations) which has standard bias correction procedures. Monahan suggested modeling the rate of successful transmissions as a function of time at the surface, and it was noted that several data sets are available that would allow this (e.g., gray seals, Weddell seals, or other data sets from recovered SLTDR's with a data logging option). A comparison of transmitted and recorded information from SLTDRs that are recovered with their recorded data is a simple approach to this problem, but to estimate bias explicit modelling of the probability of transmission as a function of surface interval would be preferred. This was acknowledged as a general, and potentially important bias with satellite telemetry data.

A second area of concern was the choice of sampling intervals employed on TDRs. Faced with some constraints in the memory capacity of TDR's, biologists have had to make a trade-off between temporal resolution and the duration of the diving records. Stewart pointed out how the sampling intervals in studies of northern elephant seals were constrained to detect surface intervals of 2 to 3 minutes. As a general rule, the sampling interval must be, at most, half the duration of the behavior one is trying to detect. Also, behaviors of short duration (e.g. surface intervals) will almost certainly be underestimated relative to behaviors of long duration (e.g., long

dives?), with the bias increasing as the sampling interval approaches the duration of the behavior. Pilot studies should be conducted with each new species and the loss of information, or bias in sampling particular behavior states should be modelled as a function of sampling interval. Also, the "information" being sampled is question-specific, and may be eroded at different rates by identical increases in sampling interval. (e.g., maximum dive duration is probably less sensitive to increasing sampling duration than multivariate analyses used to classify dives). It was also pointed out that data from the most commonly used TDRs, those provided by Wildlife Computers, are not easily filtered to simulate depths collected at longer intervals. R.Hill suggested that such data could be simulated when the TDR is downloaded by specifying that dummy sensor data was collected on channels 2 and 3. This tricks the software into ignoring part of the data set, essentially sampling it at regular intervals in order to simulate a longer depth-sampling interval.

The current practice of duty cycling (turning the TDRs on and off at regular intervals measured in days) was questioned in regard to detecting rhythms in diving or haulout behavior. R.Hill queried the group about offering random duty cycling. When the period of repetitive behavior might be unknown, an irregular sampling scheme is necessary. Monahan suggested a sampling scheme with an exponential waiting time between samples.

Brillinger contrasted the current sampling method in TDR's (testing pressure, temperature, etc. at regular intervals), with event-driven recorders used in seismology. Earthquake recorders maintain a buffer and log the entire buffer leading up to a significant seismic event.

R.Hill suggested that it may be possible to program TDRs to record accurate time marks for <u>changes</u> in a behavior state (e.g., depth reading, rate of depth changes, etc.). This approach might achieve much greater temporal resolution, but would depend on the number of state variables being measured and how regular or continuous the states are for a given animal. Some research on this is warranted.

Session IV: Parameter Estimation and Hypothesis Testing

Chair: Testa
Rapporteur: York

Analysts ask: What hypotheses do researchers want to test? Hindell responded with a "simple" example. He wants to characterize the differences among individual southern elephant seals with respect to the durations and depth of dives relative to the post-molt and post-breeding seasons. Available are 5 records of different females in each period. Others suggested simple ways to describe dives and compare various parameters (duration, maximum depth, etc.). We discussed several approaches.

Time-series vs repeated measures ANOVA: Repeated measures ANOVA assumes that the records could be described as a linear model + error, with the error having a constant autocorrelation. In the time-series approach, one tries to model the autocorrelation structure. One must find the independent and identically distributed random variables lurking in the process; i.e., express the process as a function + error, which is a stationary time-series, or a locally stationary time series ("stationary" means that the probability distribution of the process does not change, and "locally stationary" means that each part of the series is approximately stationary). One fits time-series models, such as the autoregressive integrated moving average (ARIMA), to the whole series or to the pieces. If the autocorrelation dies off, then sub-sampling will make data almost independent. If one is interested in the seasonal variation, that could be incorporated in the same way one builds linear models in regression or ANOVA.

Brillinger suggested that the first thing to do is to build a model. Because the time series are so long, it increases the probability that the assumptions of simple procedures are not satisfied. Also if one wants to use the simpler procedures, one must show that the assumptions are satisfied.

Statistical tests

Autocorrelation: Brillinger said that estimates work when data are correlated, but the correlation must be taken into account in determining their uncertainty. One can use a Durbin-Watson test for serial correlation. The variance of the mean of a stationary series is 2Đ*f(0)/n where f(0) is the value of the power spectrum at 0 frequency. However, if the series is not stationary (i.e., if the error distribution changes through time) a model must be constructed to account for the change and then the method would be applied to the residuals.

As an example, Pantula suggested that the above problem could be solved by first fitting the 24 hr cycle, thereby removing it, and then looking at the residuals. In Hindell's

data, one would compute means and variances corrected for autocorrelation for each of the females, and then use weighted ANOVA to test for seasonal differences. Monahan suggested breaking up the series and trying to model the pieces, examine how those might be similar or different from one another, then put them back together.

Brillinger's suggestion was to remove the trends, and the long-term seasonal and daily peaks, then look at the residuals; e.g., try fitting a function like $Y(t) = g(t) + a \cos(bt+h(t)) +$ error. If there are experimental groups, one would put subscripts for groups. This approach uses either ordinary or robust time-series methods; e.g., ARIMA models, or SABL or STL parameters (Box and Jenkins 1970, Harvey 1981). SABL and STL are two robust procedures for reducing a time-series into separate components, such as seasonal or diel components. The model incorporates variance structure among the parameters. With the robust procedures like SABL, the variance can be estimated using a bootstrap method on the residuals. In this case, the g or trend function and the daily values (corresponding to the "seasonal correction" in the language of the model) can be estimated by the running mean or locally weighted least squares (Cleveland 1979, Hastie and Tibshirani 1990). On data gathered in bins, as with some of the satellite-linked data, the same techniques could be used on the mean or as a multivariate time series. Controlled experiments would be modeled in the same way.

Testing for differences in the shapes of time-depth profiles: Pantula and Kelly explored this question with a least-squared differences approach by matching observed dives against 4 prototype shapes that they defined with some success, once scaling of depth and duration was taken into account. This might be a useful technique for classifying dives when the possible categories are postulated *a priori*.

Session V: Animal Movements

Chair: Brent Stewart
Rapporteur: Mark Hindell

The session began with a brief introduction of the two principle methods used to monitor the movements of seals at sea: satellite telemetry and geolocation using day-length cues. This introduction is summarized below.

There are two reasons for following the movements of seals at sea. The first is purely descriptive and aims to identify major areas used by seals and the paths used to reach these areas. The second relates to hypothesis testing. For example, "Are movements determined by physical and/or biotic factors, or are there differences in diving behavior or activity budgets according to location?"

Satellite Telemetry

The most commonly used tracking system by seal biologists is the ARGOS data collection and location system. ARGOS platforms are mounted onto NASA TIROS satellites (Television Infra-red Radiometer Observing System). The ARGOS units are particularly well suited to wildlife work, because they are low altitude satellites - only about 830km above sea level. This requires relatively little power to send a signal from a unit attached to a seal up to the satellite. The satellites have an orbit duration of 101 minutes, and at any one time the ARGOS platform can cover an area 500km in diameter. A transmitter at a location somewhere at the earth's surface is within view 10 -12 minutes on each rotation. There is also a 2800 km overlap on successive orbits.

The chances of a successful contact with a satellite depends on where the transmitter is on the earths surface. For example, a transmitter at the equator will, on average, make contact with one of the two satellites 8 times per day, while one up near the poles will make contact up to 28 times per day. Every time a transmitter successfully "talks" to a satellite it is called an uplink. You need to get at least two uplinks per pass for the satellite to calculate an accurate location - more are obviously better. The satellite calculates the position of the transmitter on the earth's surface by the Doppler shift in the frequency sent by the transmitter. The magnitude of the shift between two consecutive uplinks tells the satellite how far from the orbital track it must be. As it only gives a distance rather than a direction there are usually two possible locations for each uplink - one either side of the line of movement. Data processors in France usually examine the data and decide which is the most likely position. Depending on the number of successful uplinks per pass there are a range of predicted accuracies for any location:

1. Class 3 locations are the best possible, where 68% of the locations will be within 150m of the true locations (one standard error).
2. Class 2 locations are when 68% of the locations are within 350m of true
3. Class 1 locations are within 1 km of true.
4. Class 0 where there are no predictions made as to the accuracy of the locations - they may be "spot on", or they may be way off.

There are four possible sources of error in ARGOS locations:

1. Signal stability
2. Uplink number
3. bad geometry (i.e., directly overhead)
4. ARGOS makes the wrong decisions regarding which of the two possible locations is the most likely.

Geolocation

Data loggers can be used to estimate location by recording light intensity. Over the course of a day it is possible estimate time of sunrise and sunset (hence day length) and the time of midday. Day length data (sunrise and sunset) can be used to calculate the latitude, and time of midday provides an estimate of longitude.

The drawbacks are:

1. Only one fix per day.
2. Only accurate to at best 30 km square
3. The accuracy changes with the time of year and latitude. (For instance it is not much good for a few days either side of the equinox, or at high latitudes at those times of year when there is constant daylight.)

Discussion

A major aim of SMRU's work with satellite telemetry is to correlate diving behavior with physical features of the seals environment. There is good evidence that diving behavior is strongly influenced by factors such as bathymetry (the "shape" and depth of dives made by southern elephant seals changes over shelf areas - presumably reflecting a change in foraging strategies). Other physical factors such as thermoclines in the water column are also likely to influence dive behavior.

A specific concern of the SMRU biologists is how to best utilize class 0 records, and they are interested in developing some kind of data "screens" to remove unreliable records from the overall data set. It is therefore important to do some sort of data screening to maximize the return from ARGOS data sets.

SMRU use a screening system that assumes that seals have a maximum speed at which they can swim for a long time (3 meters

per second has been used in the past). This information is used in conjunction with an iterative process that removes outliers. Specifically the velocity at which the seal would need to have swam to reach each location is calculated for the preceding two locations and the subsequent two locations. The root mean squared of these for speeds is used as an index, and outliers are removed on an initial pass over the data, the index recalculated, and further outliers are removed. The process continues over a number of iterations until no locations remain outside a threshold index value.

There are a number of existing alternative data screens which could used for these situations, but no specific techniques were discussed. Using splines to fit curves to an animals track was proposed as one possibility. Splines are sufficiently versatile to enable a variety of 'thresholds' to be incorporated to eliminate outliers.

Integrating animal movement data with oceanographic and other environmental data was then discussed. The use of computer visualization techniques to present this type of information is a very important step in understanding the ecology of marine mammals. McConnell showed some very good examples of this kind of data presentation, using the movements and dive depths of southern elephant seals from South Georgia superimposed on a 3-dimensional representation of the Southern Ocean bathymetry using a visualization system called AVS. The bathymetry data came from a worldwide bathymetry data set called "DBDB5".

At present, detailed environmental data is the limiting step in this process (or at least access to good data). The need for a catalogue of all available data sets of this nature was expressed, to help marine mammalogists locate relevant environmental information. Also, as scientists working in other disciplines often use this sort of information, but are unaware of how useful it may be to others, the need for more collaboration between different groups was stressed.

Session VI: Overview and Directions

Chair: Ward Testa
Rapporteur: Brendan Kelly

Ward Testa opened the final session by posing three questions for discussion; (1) What did the workshop accomplish?, (2) What direction is indicated for further development of techniques for the analysis of marine mammal movements and diving behavior?, (3) What information would be most useful in the workshop report?

The chairman addressed question 1 himself by noting that the workshop made clear that a set of cohesive analysis protocols would not suffice for the variety of data being collected with TDRs and related instruments. Rather, each research project will require unique data analyses that suit the specific research questions, the behavior of the species under consideration, and the required technical approach. At the same time, there was unanimous agreement that the workshop made obvious many similarities in the problems faced by different researchers and that a significant start had been made at addressing some of those problems. For example, the dive classification strategies attempted by some of the subcommittees showed promise as consistent, objective methods of typing dive profiles. The workshop improved the participating biologists' knowledge of appropriate methods of time series analysis necessary for full analysis of existing dive data.

Bernie McConnell and Roger Gentry stressed that the workshop's greatest accomplishments involved connecting marine mammal researchers with statisticians expert in appropriate methods. The biologists gained a better appreciation of the types of statistical techniques appropriate to movement and dive data. References provided by the statisticians and on-going consultations will further edify biologists in this field. The workshop format was highly successful at communicating to the consulting statisticians the range of analysis problems faced by biologists working with marine mammal dive data.

The group unanimously agreed to continue by electronic mail the statistical consultation begun in this meeting. Ward Testa agreed to keep data sets provided by participating biologists available on the common "SEAL" directory available through Internet (Appendix B). He requested that, with each added data set, an explanatory "README" file be provided. Using those data, teams of statisticians and biologists are addressing specific areas (Appendix C). As the problems and methods unfold, each team will update others, and there likely will be fluidity in team composition.

These collaborations are expected to improve the analysis of the data sets discussed during the workshop and, moreover, to provide models for other workers analyzing dive data from a

variety of marine organisms. Therefore, it was the recommendation of the participants that we re-convene in one year to discuss the results of analyses formulated in the first meeting and to formalize recommendations to colleagues analyzing similar data sets.

Costa suggested that the Office of Naval Research would consider funding such a follow-up workshop, and that it would be appropriate to choose a convener to submit a proposal. Three venues were suggested. Stewart pointed out that the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) is interested in conducting a related workshop and that it might be efficient to combine efforts. Gentry explained that CCAMLR's interest is more narrow, focusing mainly on standardizing terminology, and he stressed the need for a forum, such as this workshop, suitable to "brain-storming" new analysis techniques. It also was agreed that the limited size of the current group was invaluable to its effectiveness.

Kelly suggested that the next venue should be equipped with computer laboratory that would facilitate group interaction while working directly with data sets. Ideally, the facility would include a laboratory with ten or more personal computers in a network and communicating via Internet to the participants' different home-based computers. Also desirable would be the ability to project computer screens for easy viewing by the entire group. Suitable computer laboratories exist at the University of Waterloo and North Carolina State University. Kit Kovacs and John Monahan offered to convene the next workshop at those respective institutions. A steering committee, consisting of Ward Testa, Kit Kovacs, and John Monahan was appointed to consider the venue and develop a proposal to the Office of Naval Research.

The group anticipates that the next workshop will produce one or more publications in the form of methods papers aimed at facilitating data analysis by researchers collecting movement and dive data collected by TDRs and similar instruments. The publications will not be manuals per se, but summaries of the methods available to handle a variety of analysis problems common to these data sets.

Discussion of the current report focused on its usefulness to the workshop participants themselves and to colleagues not present. For the workshop participants, the report should summarize each session and serve as a reference for which subgroups continue to deal with which analysis problems. For our colleagues at large, we would hope this report is useful as an indication of approaches being taken in the analysis of diving data, and to encourage them to share their problems and/or solutions in analyzing remotely recorded movement and dive data.

References

Bloomfield, P. 1976. Fourier Analysis of Time Series: An Introduction. Wiley and Sons, New York.

Box, G.E.P. and G.M. Jenkins. 1970. Time Series Analysis. Holden-Day, 553p.

Cox, D.R. and P.A.W. Lewis. 1966. The Statistical Analysis of Series of Events. Methuen, 285p.

Cleveland, W.S. 1979. Robust locally weighted regression and smoothing scatterplots. J. American Statistical Assoc. 74: 829-836.

Harvey, A.C. 1981. Time Series Models. Wiley and Sons, New York.

Hastie, T. and R. Tibshirani. 1990. Generalized Additive Models. Chapman and Hall, 335p.

Hawkins. 1987. Self starting cusum charts for location and scale. The Statistician 36: 299-315.

Kendall, M.G. and J.K. Ord. 1990. Time Series. Oxford Press, 296p.

Lucas, J.M. and M.S. Saccucci. 1990. Exponentially weighted moving average control schemes: properties and enhancements. Technometrics 32: 1-12.

Pettitt, A.N. 1979. A non-parametric approach to the change-point problem. Applied Statistics 28: 126-135.

Quandt. 1958. The estimation of the parameters of a linear regression system obeying two separate regimes. American Statistical Assoc. Journal 53: 873.

Shell, R.L. (ed.) 1986. Work Measurement: principles and practice. Industrial Engineering and Management Press.

Snyder, D.L. 1975. Random Stochastic Point Processes. Wiley, New York, 485p.

Weisberg, S. 1985. Applied Linear Regression. Wiley and Sons, New York, 283p.

APPENDIX A. SAMPLING CONSIDERATIONS WITH TDRs AND SLTDRs

The aim of this document is to propose a framework for discussing the problems related to the sampling processes encountered when studying marine mammals using TDRs and SLTDRs. The framework should also be appropriate for other telemetry systems such as VHF and ultrasonic.

Before considering data SAMPLING STRATEGIES we should first be clear what QUESTIONS are being addressed. These questions are then used to SPECIFY the required OUTPUT. The initial question may just involve getting some first understanding of the 'natural history' of the beast under study. Nevertheless we should still go through the formal routine of deciding in advance what type of data are required. The end result should always enable an UNAMBIGUOUS reconstruction of some aspect of behaviour.

The process of sampling underlies all data gathering and we should always be aware of the problems of BIAS and ERROR. This document is based on the various stages of data sampling. The scheme attempts to be global, covering TDRs and other devices which transmit data.

1. LOCATION / SEASON / DURATION

The first sampling choice is what population is to be studied and when and over what duration is the study to take place. Are some aspects of behaviour population or season specific? Is the anticipated duration sufficient to detect the event the event being studied (eg 2-4 days fur seal foraging trips cf six month elephant seal migrations)?

2. INDIVIDUAL

What sample of individual seals do we study? Is behaviour age or sex specific? Does the capturing technique bias the sample in favour of those individuals most readily caught; i.e., the 'thick or sick' or those spending a greater proportion of their time ashore. How many individuals should be studied?

3. DATALOGGER

How does the datalogger sample seal behaviour (and its environment) and get the information back to the investigator? Three separate stages may be involved: ACQUIRING, PROCESSING and TRANSMITTING.

3.1 ACQUISITION is the process of getting data from sensors (including a clock). In general the interval between interrogations (samples) should be less than half that of the duration of the EVENT being detected in order to avoid ALIASING. However too high an interrogation frequency is wasteful of energy and may be better replaced with an

interrupt driven sampling system. The sampling may be context specific. For example there is little point in interrogating a depth sensor when a submergence sensor is dry. However a dry submergence sensor indicates a good time to recalibrate the depth sensor to zero depth.

3.2 The degree of on-board PROCESSING of the acquired data is determined by two factors: A PRIORI knowledge of behaviour and the rate at which data can be transmitted. If a priori we know nothing about a behaviour then we should relay all acquired data. If we have a good a priori understanding then we can carry out on-board processing and only relay statistics of the acquired data. One way to process the data is to classify activity into 'haulout', 'at surface' and 'diving'. This classification is fairly simple to formalize and code, albeit arbitrarily. The shape of a dive against time can be obtained in different ways. ALL or a SUBSET of the data may be relayed. Alternatively certain EVENTS such as inflection points may be defined detected and then relayed. It is vital, however that such definitions are appropriate for all dive types encountered.

Ultimately, though unwisely, we could carry out an ON-BOARD dive classification / ordination procedure such as Principal Components Analysis.

3.3 non TDR: not all acquired and processed data are transmitted. To extend transmitter life DUTY CYCLING may be used. Again the duty cycling period must be carefully chosen to avoid aliasing problems (eg the detection of diurnal variation in behaviour) and should take into account the POWER BUDGET of the datalogger/transmitter. Should data acquired during the periods when transmissions are inhibited be transmitted? Should data acquisition also be duty cycled? Are SUMMARY statistics for OFF periods required?

4. RECEIVED DATA

Data may be RECEIVED by investigator by recovery of the datalogger and reading MEMORY, or they may be relayed by TRANSMISSION. In the first instance unless all the deployed dataloggers are recovered there is the possibility of a sampling bias towards those seals which return to known and accessible locations, and then to those which can be recaptured.

When data are transmitted, by whatever means, only a sample of the population of transmissions is actually received. Some transmissions are lost due to DATA TRANSMISSION ERRORS which must be detected and possibly corrected. Others are lost due to being out of range of the receiver (ultrasonic, VHF or UHF satellite). This has important consequences. First, it is important that each transmission can be decoded independently of others. Second, since VHF/UHF transmissions are limited to surface intervals there may be a bias in favour of dives types with longer surface intervals. To investigate such biases SUMMARY

STATISTICS of dive records over some set period can be transmitted sufficiently frequently to guarantee that at least one summary record is successfully relayed for every period. What period is most appropriate?

How large should our sample size of dive records be? ALL dives can only be relayed via Argos at a very high cost. How important is to relay a CONTIGUOUS series of dives? The answers to these sampling questions must relate to the TIME SCALE of behaviour. For instance a system which used a DUTY CYCLING regime of one day on and two off would be appropriate for the long distance travels of an elephant seal but inappropriate for a nursing fur seal making two day foraging trips. As with data acquisition, the duty cycling period should be less than half that of the duration of the EVENT being detected in order to avoid ALIASING.

5. ANALYSIS

By fair means or foul we have got data into the lab. Sampling considerations still apply. Do we have to sub-sample dive records into smaller data sets to analyze then. If so how? Stratified or unstratified? A second type of 'sampling' is the filtering out of erroneous data. For example LQ class 0 Argos locational data can be very significantly improved by a variety of LOCATION FILTERING algorithms (eg Kalman, SMRU).